Comparison of Wallingford (DRAMBUIE) Scour Predictions with Measurements

P.A. Elmore[1], C. T. Friedrichs[2], M.D. Richardson[1], P.A. Traykovski[3], K.B. Briggs[1]

[1]Naval Research Laboratory, Marine Geosciences Division, Stennis Space Center, MS 39529
[2]Virginia Institute of Marine Science, College of Marine Science, Department of Physical Sciences, Gloucester Point, VA 23062
[3]Woods Hole Oceanographic Institute, Applied Ocean Physics and Engineering Department, Woods Hole, MA 02543

ABSTRACT

The equations that are the basis of the DRAMBUIE scour model were developed at H.R. Wallingford (a U.K. civil engineering firm) and have been published in works by Soulsby (1997) and Whitehouse (1998). We present their equations for predicting scour when both waves and currents are involved and show the predictions with measurements taken from the NRL instrumented mine. The predictions match well with three deployments of the instrumented mine. A fourth deployment is ongoing.

THEORY

A. Main equations

$$S(t) = S_\infty\left(1 - \exp\left(-t/T\right)^p\right)$$

- $S(t)$ = depth of scour pit at time t
  S_∞ = scour pit depth at t = ∞
  T = time constant governing rate of growth
  p = 0.6, geometric parameter
- S_∞ is found by the equations in Block B
- T is found by the equations in Block C
- Time stepping and use for burial depth is shown in Block D.
- Burial depth is the maximum scour depth over the deployment period minus the amount of re-exposure

$$B_D(t) = \max(S(t)) - \alpha S(t)$$

List of Symbols

A, B = Geometric coeff., A = .095, B=-2.02
B_D = mine burial depth
C_r = drag coefficient for total stress
D_0 = mine diameter
d_{50} = median grain diameter
f_w = wave friction factor
g = gravitational acceleration
h = water depth
p = 0.6, geometric parameter
S = scour pit depth at time t
S_∞ = scour pit depth at t = ∞
s = ρ_s/ρ_w
T = time constant for rate of scour pit growth
t = time
U = mean velocity at the seabed
$\overline{U}$ = depth averaged current velocity
U_b = mean orbital velocity
U_{cr} = critical velocity for sediment transport
T_w = mean wave period
z = sensor depth
α = 0.6, efficiency for scour to re-expose a buried mine
θ = Shield's parameter
θ_{cr} = critical Shield's parameter for sediment transport
θ_∞ = Shield's parameter when no mine is present
ρ_s = sand density
ρ_w = water density
τ = stress
τ_c = stress due to current alone
τ_{cr} = critical stress for sediment transport
τ_m = nonlinearly combined stress from τ_c and τ_w
τ_w = stress due to waves
ϕ = angle between current and waves

B. Obtaining S_∞:

- S_∞ is found from

$$S_\infty = \begin{cases} 0, & U < 0.75U_{cr} \\ 1.15D_0\left(2U - 1.5U_{cr}\right)/U_{cr}, & 0.75U_{cr} < U < 1.25U_{cr} \\ 1.15D_0, & U > 1.25U_{cr} \end{cases}$$

- U can be measured directly, but U_{cr} is not directly obtainable
- Change variables in S_∞ from U and U_{cr} to Shield's parameters θ and θ_{cr}, which can be evaluated
- Stress at the bed is

$$\tau = \rho_w C_r U^2$$

- The Shield's parameter is

$$\theta = \tau/\left((\rho_s - \rho_w)gd_{50}\right)$$

- At U_{cr},

$$\tau \to \tau_{cr} = \rho_w C_r U_{cr}^2$$
$$\theta \to \theta_{cr} = \tau_{cr}/\left((\rho_s - \rho_w)gd_{50}\right)$$

- Thus $U/U_{cr} = (\theta/\theta_{cr})^{0.5}$ so that

$$S_\infty = \begin{cases} 0, & \sqrt{\theta} < 0.75\sqrt{\theta_{cr}} \\ 1.15D_0\left(2\sqrt{\theta} - 1.5\sqrt{\theta_{cr}}\right)/\sqrt{\theta_{cr}}, & 0.75\sqrt{\theta_{cr}} < \sqrt{\theta} < 1.25\sqrt{\theta_{cr}} \\ 1.15D_0, & \sqrt{\theta} > 1.25\sqrt{\theta_{cr}} \end{cases}$$

$$\theta = \tau/\left((\rho_s - \rho_w)gd_{50}\right)$$

$$\tau = \left[(\tau_m + \tau_w\cos\phi)^2 + (\tau_w\sin\phi)^2\right]^{0.5}$$

$$\tau_m = \tau_c\left[1 + 1.2\left(\frac{\tau_w}{\tau_c + \tau_w}\right)^{3.2}\right]$$

$$\tau_c = \rho_w C_D \overline{U}^2$$

$$\tau_w = 0.5\rho_w f_w U_b^2$$

$$f_w = 1.39\left(6U_bT_w/\pi d_{50}\right)^{-0.52}$$

$$C_D = \left[\frac{0.4}{1 + \ln(12h/d_{50})}\right]^2$$

$$U(z) = \begin{cases} (z/0.32h)^{1/7}\overline{U}, & 0 < z < 0.5h \\ 1.07\overline{U}, & 0.5h < z < h \end{cases}$$

$$\theta_{cr} = \frac{0.3}{1 + 1.2D_*} + 0.055\left(1 - \exp(-0.02D_*)\right)$$

$$D_* = d_{50}\left((s-1)g/\nu^2\right)^{1/3}$$

C. Obtaining T:

- Time constant has been empirically determined to be

$$T = T^*\left((s-1)gd_{50}^3\right)^{-1/2}D_0^2$$

where

$$T^* = A\theta_\infty^B$$

- A = 0.095 and B = -2.02 for a 5:1 cylinder, thus

$$T = A\theta^B\left((s-1)gd_{50}^3\right)D_0^2$$

D. Time Stepping and Burial Depth:

- Rewrite the Main Equation in Block A as a time stepped calculation. For the j+1th time interval,

$$S(t_{j+1}) = S_\infty(t_j)\left(1 - \exp\left(-(t+\Delta t)/T(t_j)\right)^p\right)$$

where the steady-state time to get to $S(t_j)$ is

$$t = T(t_j)\left(-\ln\left(1 - S(t_j)\right)/S_\infty(t_j)\right)^{1/p}$$

- Set an upper limit to the scour depth for the j+1th step

$$S(t_{j+1}) = \begin{cases} S_\infty(t_j)\left(1 - \exp\left(-(t+\Delta t)/T(t_j)\right)^p\right), & S(t_j) < S_\infty(t_j) \\ S_\infty(t_j), & S(t_j) \geq S_\infty(t_j) \end{cases}$$

- Burial is the maximum scour depth achieved minus the re-exposure.

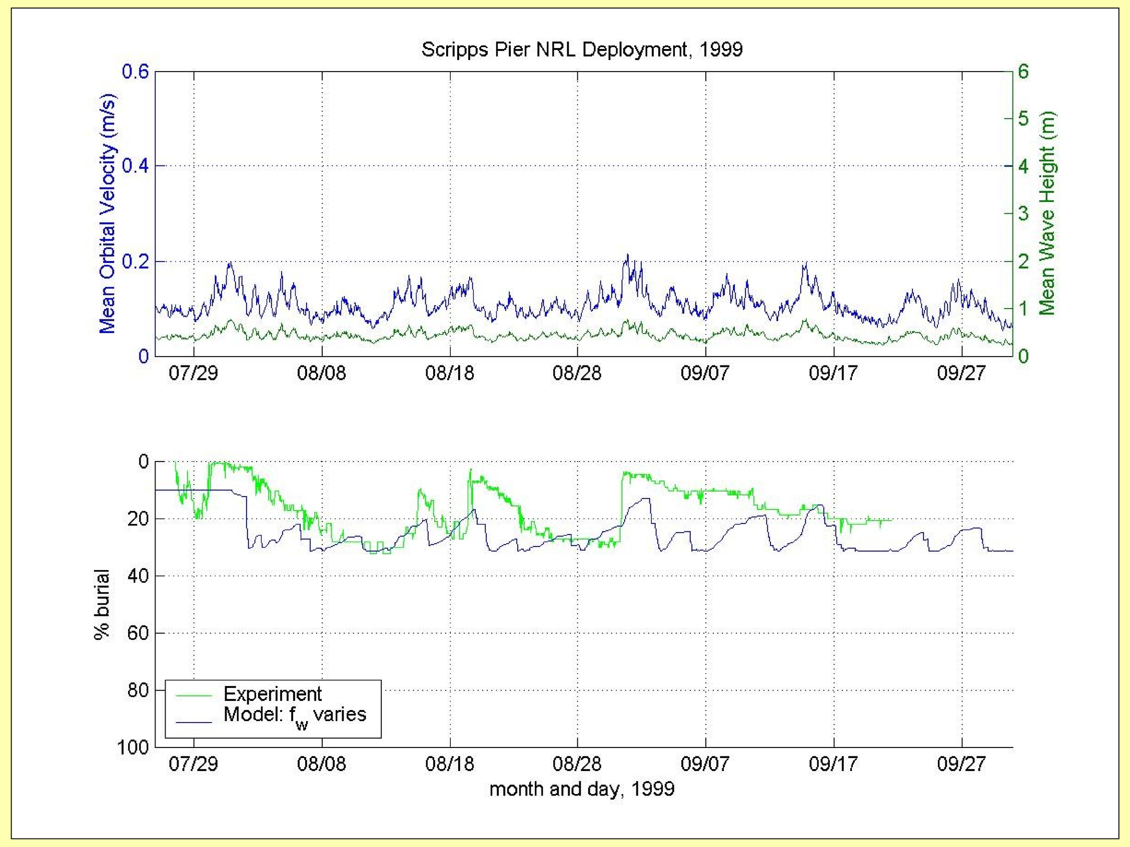
$$B_D(t_j) = \max\left(S(t \leq t_j)\right) - \alpha S(t_j)$$

COMPARISON OF PREDICTION WITH MEASUREMENT

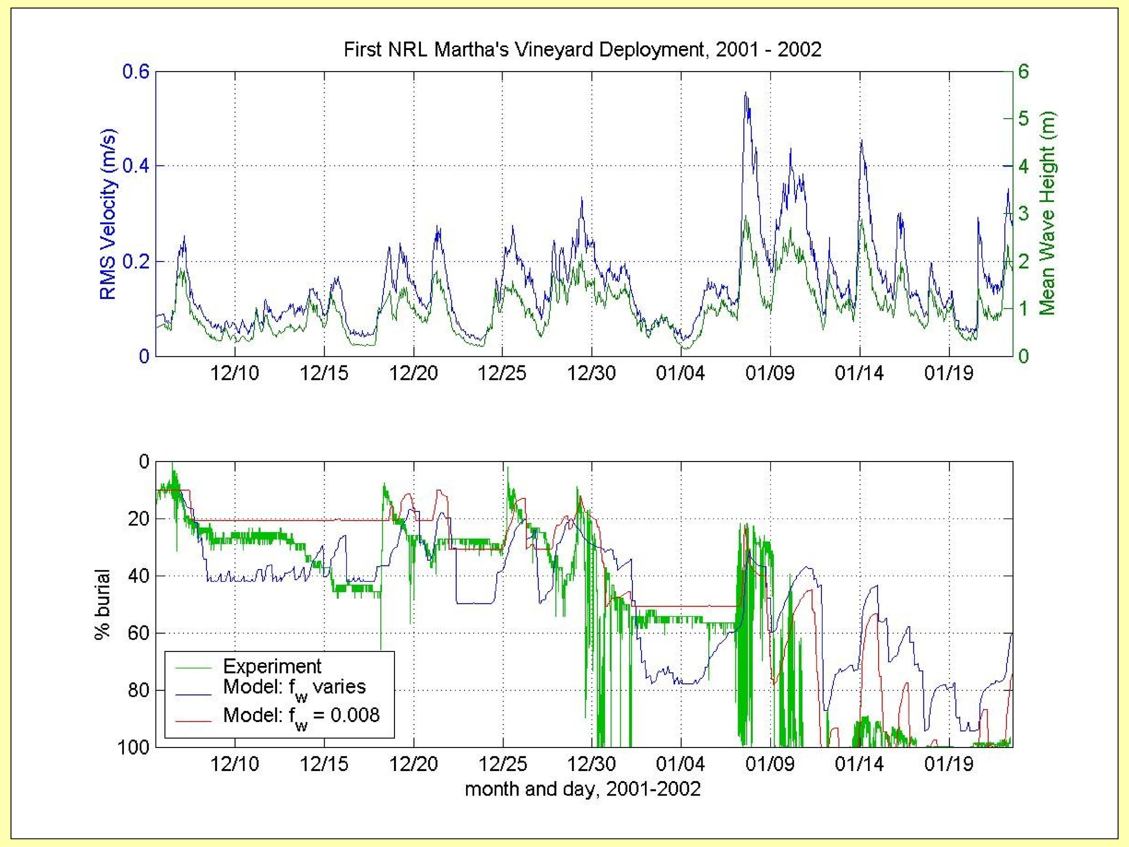
The NRL instrumented mine being deployed at Martha's Vineyard Coastal Observatory (MVCO).

The NRL instrumented mine (pictured at the left) is being used to measure burial by scour. Three sets of deployments have been completed, one at Scripps Institute of Oceanography in 1999 and two at Martha's Vineyard Coastal Observatory (MVCO) in 2001 and 2002. A third deployment is underway at MVCO. The mine has three sets of optical sensors about the circumference, one set in the middle and two at either end. The intensity of light is measured and recorded by internal electronics, so the amount of burial is the determined by the blockage of light.

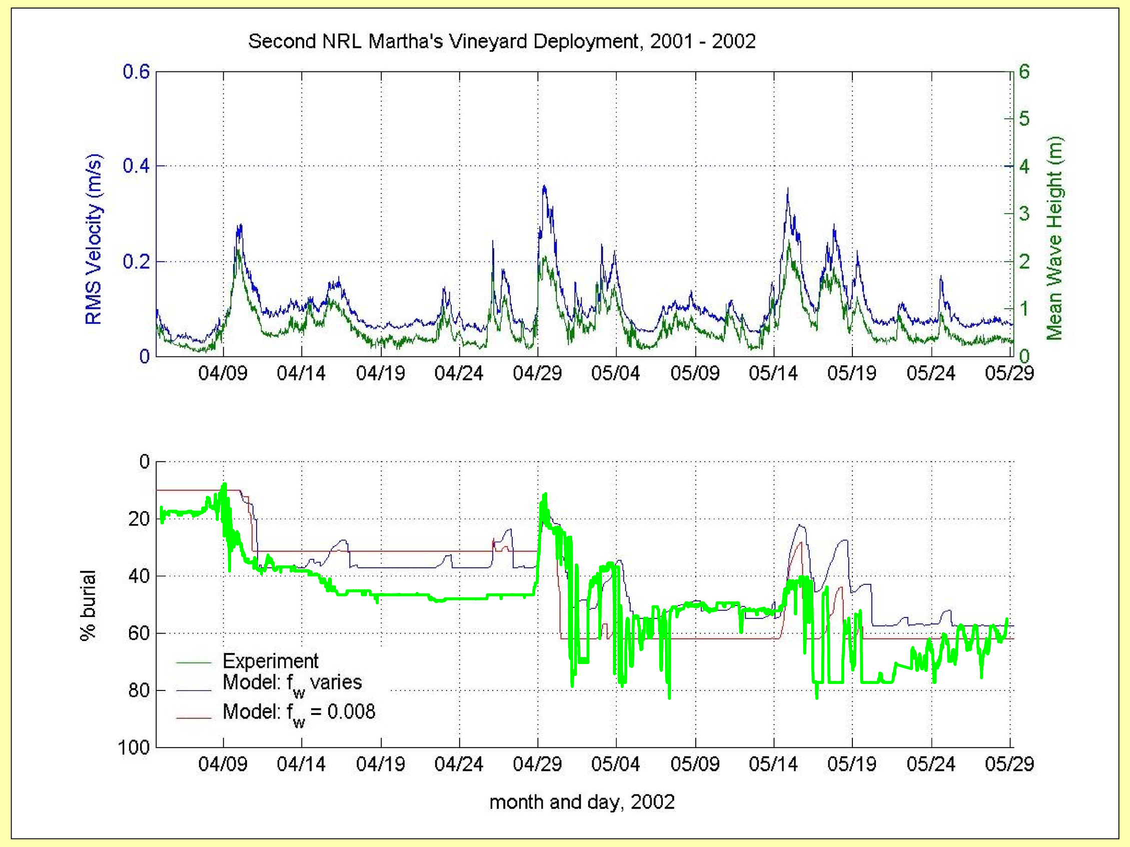
The scour model was run with velocity data and wave period measured by ADCP and ADV sensors. The results for the three completed deployments and the ongoing third MVCO deployment are shown with velocity and wave height data. Two set of calculations were run for MVCO. One (red) has f_w = 0.008; the second (blue) has f_w determined from wave height and period data.Tidal currents are assumed to have an insig



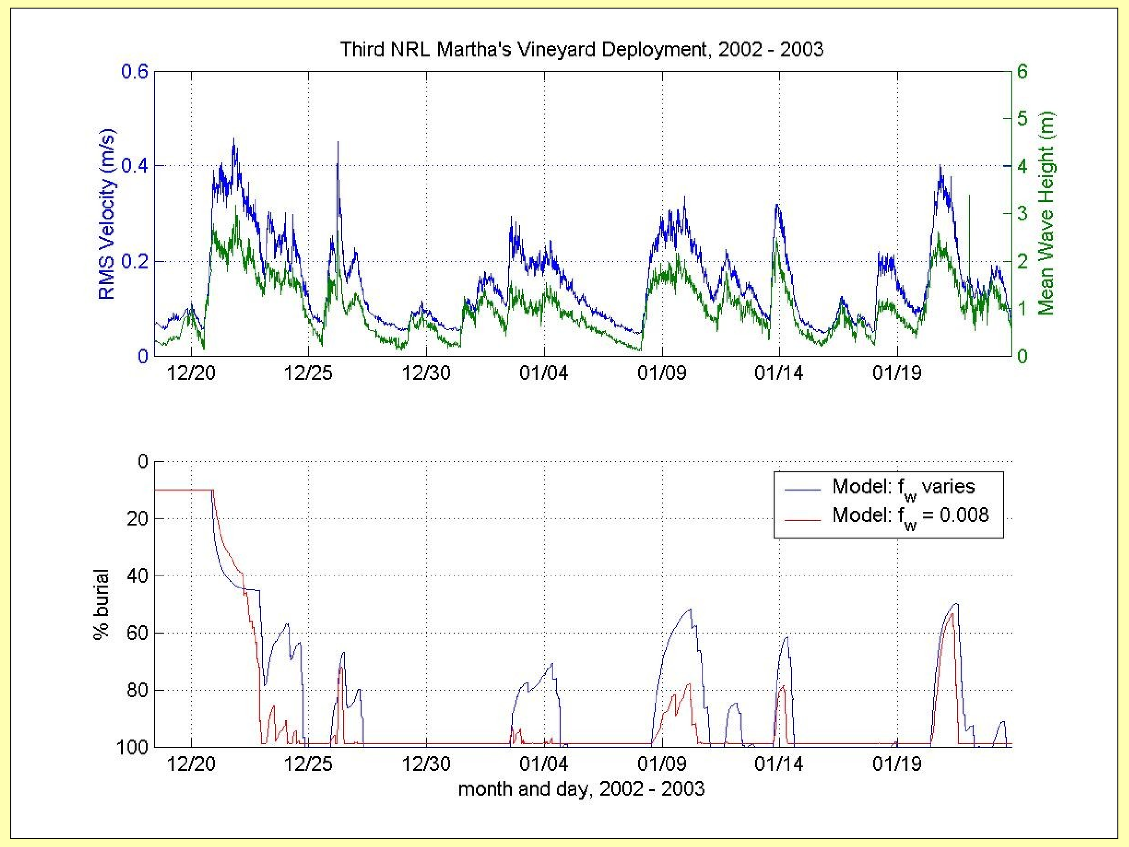
Completed deployment at the Scripps Institute of Oceanography, Summer 1999. Median grain diameter = 0.19 mm. Model run for varying f_w only.



First completed deployment at Martha's Vineyard Coastal Observatory, Winter 2001-2002. Median grain diameter = 0.18 mm.



Second completed deployment at Martha's Vineyard Coastal Observatory, Spring 2002. Median grain diameter = 0.18 mm.



Third deployment (predictions only) at Martha's Vineyard Coastal Observatory, Winter 2002-2003. Median grain diameter = 0.60 mm. This deployment is still in progress.

CONCLUSIONS

The HR Wallingford equations appear to be promising for predicting the scour of a free body cylinder in sand with grain sizes on the order of 0.2 mm. We still need to compare the model output with the mine data for the third MVCO deployment, which is on coarser sand (0.5 mm), and evaluate the usefulness of including tidal currents. The model is simple and mature enough to be considered for integration into first generation holistic prediction systems.

Further work is required, however, to make the model more applicable to a wider variety of mines. At the moment, the geometrically determined parameters in the equations are given only for 5:1 cylinders. Work is required to examine the sensitivity of the model output to uncertainty of these parameters, and determine what these parameters may be for other mine geometries if a significant sensitivity is detectable. Another refinement that is needed is to account for the decreasing cross-section of the mine above the seabed as it scours into the sediment instead of the currently working assumption of a constant cross-section.

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